Title of Invention

Method for Producing Lightweight Alloy Stock for Impact Extrusion

Cross Reference to Related Applications

This application is a continuation-in-part of U.S. Ser. No. 09/681,076, filed Dec. 22, 2000.

Statement Regarding Federally Sponsored Research or Development

Not Applicable

Background of Invention

(001) The primary objective of this invention is to provide a method for producing a suitable lightweight starting stock that can be used for impact extrusion or impact forging. Another objective is to provide a method for producing a lightweight aluminum starting stock that provides high strength once the starting stock is impact extruded. It is yet another objective to provide a method for producing a lightweight aluminum alloy starting stock that can be heat treated to provide high strength impact extrusions in a number of unique sizes and shapes. A final objective is to provide a method for producing a lightweight aluminum alloy starting stock that, once fabricated into an impact extruded shape, provides enhanced performance in the final product by virtue of higher strength properties.

Brief Summary of the Invention

(002) This invention provides a method to produce an aluminum alloy starting stock alloy that can readily be manufactured into impact extrusions (also known as impact forgings) wherein said impact extrusions are readily fabricated into cost effective components that possess high strength. Another objective of this invention is to attain strength levels heretofore unachievable in aluminum alloy impact extrusions to enable designers to reduce the cross section size of impact extruded components to reduce weight. Another objective of this invention is to provide an aluminum alloy starting

stock that can be readily impact extruded into a number of shapes that are capable of attaining strength properties greater than or equal to that achieved in various steel alloys. In this instance, the impact extrusion of this invention can be produced to a similar size and shape as the steel impact extrusion. The high strength properties would ensure similar or enhanced performance of said impact extrusion while the inherently low density of the aluminum alloy relative to steel would enable a weight reduction of at least 60%.

(003) While the scope of this invention is oriented toward the development of starting stock that is suitable for the process of impact extrusion, it should be noted that the strength levels attained and the accompanying performance attributes can enable the use of this invention for other downstream cold forming processes, for example stamping, impact forging, rolling, swaging, explosive forming and drawing. In these processes, the unique combination of cold formability and ultra-high strength are anticipated.

Brief Description of the Drawings

Not Applicable

Description of Prior Art

(004) Impact extrusion is accomplished by utilizing a punch that is rapidly forced through a metal slug starting stock. The metal slug can be constrained such that metal flows into a shape mandated by the shape of the penetrating die, thereby causing metal to flow upward around the punch. Alternatively, the metal slug can be forced through an orifice of a die so that the slug takes the shape of the die. A combination impact utilizes a penetrating punch in combination with a die to accomplish both forward and reverse metal flow. The process of impact extrusion is especially amenable to producing cylindrical hollow shapes with a closed end. Applications include automotive

parts such as airbag canisters and shock absorbers, components in household appliances and military applications such as missile casings.

(005) When utilizing aluminum alloy starting stock for the impact extrusion process, soft alloys such as commercially pure aluminum are used in most applications. Commercially pure aluminum, by virtue of the low alloying content, has a combination of low strength and high elongation. This highly ductile material is amenable to large impact extrusion reductions that are advantageous for a number of final part geometries. Because it is desirable to blend the high rate production capabilities of impact extrusion with the use of higher strength alloys, several endeavors have been undertaken to develop improved alloys amenable to impact extrusion.

(006) U.S. Pat. No. 4,243,438 to Yanagida et.al. describes and method of producing an impact extrusion using an aluminum alloy slug comprised of <3.0% of at least one element selected from cobalt and nickel. The primary focus of this invention is an increase of ductility of the new alloy after annealing to affect an improvement in fabrication characteristics. The highest strength level reported in this invention is 20.7 kg/mm^2 or 28.5 ksi.

(007) U.S. Pat. No. 5,961,752 to Bergsma describes a high strength Mg-Si type aluminum alloy, methods of casting and thermo mechanical processing sequences. In Example 8, an aluminum alloy with a composition of 0.91 Si, 0.17 Fe, 0.78 Cu 1.41 Mg, 0.22 0.10 V, 0.0006 Be, balance aluminum, was cast into an ingot, homogenized and cold impact extruded into a hollow shape. Subsequent heat treatment resulted in a yield strength value of 59 ksi, tensile strength of 64 ksi and elongation of 18%.

(008) U.S. Pat. No. 5,221,377 to Hunt et.al. provides an alloy product consisting essentially of 7.6 to 8.4% Zn, 1.8 to 2.2% Mg, 2.0 to 2.6% Cu and at least one element selected from Zr, V, and Hf in a total amount not exceeding 0.5%. High yield strength properties were achieved in both plate (85-86 ksi) and extrusion (89-90 ksi) products. Forged products are anticipated by Hunt in claims 125 to 129, and anticipated yield

strength values are presented as a percentage increase over the properties of alloy 7050 forgings shown in Table 5 of the patent application. When calculating the percent increase in yield strength, the highest value in the table, 63 ksi, is multiplied by the highest percent increase anticipated by Hunt (15%). Accordingly, the highest strength anticipated is 63 ksi x 1.15 or 72.5 ksi. It should be noted that the production of extrusion, plate and forgings are comprised of warm and or hot working operations. The use of this alloy for an impact extrusion, a process performed at ambient temperature, was neither taught nor anticipated by Hunt.

(009) U.S. Ser. No. 09/681,076 to Tack et.al. provides a method for producing a suitable lightweight starting stock that can be used by gun manufacturers for gun frames and components. A combination of alloying elements is blended with various processing sequences to produce a high strength gun frame or gun component. The primary emphasis is the use of conventional forging practices that are conducted at an elevated temperature for the specific purpose of producing gun frames and components.

Brief Description of Sequences

(010) An objective of this invention is to provide an aluminum alloy starting stock for impact extrusion that meets the following criteria:

An optimum combination of alloying elements for good strength and elongation,

A starting stock with a combination of a favorable microstructure, a minimum amount of defects and a favorable heat treatment practice to enable impact extrusion fabrication into complex shapes without premature failure,

A suitable heat treatment sequence to impart high strength on the impact extruded part.

(011) Suggested processing steps and the accompanying purpose are as follows:

Processing Step	Purpose
1) Casting of Billet	Provide mixture of alloying elements
2) Homogenize Billet	Refine as-cast structure
3) Extrude into bar	Breaks down the as-cast microstructure and orients the grains parallel to the direction of subsequent impact extrusion, heals any internal casting defects to provide a sound starting stock for impact extrusion
4) Anneal extruded bar	Softens the extruded bar to provide a low yield strength and increased elongation to enable impact extrusion fabrication into complex geometries
5) Impact extrusion	Provide final shape or intermediate shape for the desired part geometry
6) Solution Heat Treat	Place alloying elements into solid solution
7) Quench	Achieve metastable solid solution
8) Artificial Age	Promote precipitation strengthening

(012) While the aforementioned processing steps are the core principle of this invention, it should be noted that the injection of ancillary processing steps into the sequence are anticipated. As one example, a machining operation can be used after extrusion or annealing (steps 3 and 4) to further modify the starting stock in preparation for impact extrusion. The impact extrusion step itself can be conducted in one step or multiple steps. For multiple impact extrusion steps, the initial starting stock can be

annealed and subjected to impact extrusion to attain and intermediate shape. This intermediate shape can then be annealed and subjected to a further reduction and shape change by utilizing another set of dies. Once a multi-step impact extrusion is completed, the final sequences of solution heat treatment, quenching and aging are applied to achieve high strength in the final part. It is acknowledged that machining operations can be applied throughout the multi-step impact extrusion sequence, prior to the final heat treatment or following the heat treatment sequence. Finally, other forming processes such as drawing or ironing can be accomplished on intermediate or final impact extrusion forms to achieve a final shape.

Detailed Description of the Invention

(013) According to the present invention, a method for producing lightweight starting stock for impact extrusion is provided. In a preferred embodiment of the invention, an alloy is selected that is comprised of primary elements Zn, Mg and Cu combined with grain refining elements Zr, Cr and Sc, with the balance consisting of aluminum. The elements are blended together in the appropriate ratios and direct chill cast into billets. After the billet is homogenized, it is heated to an elevated temperature and extruded. The extrusion is then annealed to soften the starting stock for subsequent impact extrusion. If multiple impact extrusion steps are necessary, it is advantageous to anneal the intermediate forms prior to each impact extrusion step to affect larger impact extrusion reductions. Once the final shape is attained, the alloy is solution heat treated, quenched and subjected to artificial aging. Machining operations can be introduced at any point in the manufacturing sequence to improve the impact extrusion stock surface to enhance the initial fit-up into the next impact extrusion die.

Detailed Description of the Preferred Embodiments

(014) In accordance with this invention, the impact extrusion starting stock is an aluminum alloy consists essentially of about 5.0 to 11.0% Zn, 1.0 to 3.5% Mg, 0 to 2.8% Cu and lesser amounts of grain and structure refining elements including Zr, Ti, Cr, Mn and Sc.

(015) Example 1:

Mechanical Properties of Starting Stock, Alloy 1: The alloy formulation shown in Table 1 was direct chill cast into billets. The alloy formulation was selected to provide a high level of primary alloying additions Zn, Mg and Cu along with dispersoid-forming elements Zr, Sc and Cr. The billets were then homogenized, pre-heated to 650°F and extruded into round bars with a 1.5-inch diameter. The 1.5-inch diameter bar was then subjected to the following heat treatment:

Solution heat treatment at 875°F for 1 hour,
Water Quench,
Hold at Ambient Temperature for 72 Hours,
Age at 250°F for 8 hours followed by 320°F for 8 hours (treatment A), or
Age at 250°F for 24 hours (treatment B).

[Table 1: Composition of Alloy 1 Starting Stock (weight %)]

Zn	**Mg**	**Cu**	**Zr**	**Ti**	**Cr**	**Sc**	**Al**
7.75	1.83	1.75	0.114	0.015	0.029	0.07	balance

(016) As shown in Table 2, the mechanical properties of this alloy formulation indicate that ultra-high strength is attainable. The alloy also displays a good elongation considering the high strength levels attained.

[Table 2: Mechanical Properties of Alloy 1 Starting Stock]

Heat Treatment	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)
A	92.3	94.5	13.8
B	99.5	105.0	13.0

(017) Example 2:

Mechanical Properties of Starting Stock, Alloy 2: The alloy formulation shown in Table 3 was direct chill cast into billets. The alloy formulation was selected to provide a high level of primary alloying additions Zn, Mg and Cu and dispersoid-forming element Zr. The billets were then homogenized, pre-heated to 700°F and extruded into round bars with a 2.25-inch diameter. The 2.25-inch diameter bar was then subjected to the following heat treatment:

Solution heat treatment at 875°F for 1 hour,

Water Quench,

Hold at Ambient Temperature for 48 Hours,

Age at 250°F for 24 hours.

[Table 3: Composition of Alloy 2 Starting Stock (weight %)]

Zn	Mg	Cu	Zr	Ti	Cr	Al
8.17	2.22	1.65	0.099	0.039	0	balance

(018) As shown in Table 4, the mechanical properties of this alloy formulation indicate that ultra-high strength is attainable. The alloy also displays a good elongation considering the high strength levels attained.

[Table 4: Mechanical Properties of Alloy 2 Starting Stock]

Heat Treatment	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)
B	100	105	7.0

(019) Example 3:

Mechanical Properties of Starting Stock, Alloy 3: The alloy formulation shown in Table 5 was direct chill cast into billets. The alloy formulation was selected to provide a high level of primary alloying additions Zn, Mg and Cu and dispersoid-forming elements, Zr, Sc and Cr. For this alloy variant, an unusually high alloying amount of Zn was provided for extra solid solution and precipitation strengthening. The billets were then homogenized, pre-heated to 700°F and extruded into round bars with a 2.25-inch diameter. The 2.25-inch diameter bar was then subjected to the following heat treatment:

Solution heat treatment at 875°F for 1 hour,
Water Quench,
Hold at Ambient Temperature for 48 Hours,
Age at 250°F for 24 hours.

[Table 5: Composition of Alloy 3 Starting Stock (weight %)]

Zn	Mg	Cu	Zr	Ti	Sc	Cr	Al
9.1	2.4	1.66	0.096	0.04	0.09	0.04	balance

(020) As shown in Table 6, the mechanical properties of this alloy are remarkably high for an aluminum alloy as indicated by the yield strength of 105 ksi and tensile strength of 111 ksi. The alloy also displays a good elongation of 8.0%, a substantial accomplishment in view of the fact that such high strength levels are attained.

[Table 6: Mechanical Properties of Alloy 3 Starting Stock]

Heat Treatment	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)
B	105	111	8.0

(021) Example 4:

Mechanical Properties of Starting Stock, Alloy 4: The alloy formulation shown in Table 7 was direct chill cast into billets. The alloy formulation was selected to provide an intermediate level of primary alloying additions Zn and Mg; Cu was removed to create an alloy formulation with good weldability. Dispersoid-forming elements, Zr, Sc and Cr were added to provide grain refinement. The billets were then homogenized, pre-heated to 750°F and extruded into round tube with a 2.5-inch diameter, and drawn to a 1.375-inch diameter with a wall thickness of 0.060-inch. The purpose of producing this shape is to progress into the practice of multiple drawing and annealing steps to access the potential of this alloy for impact forging applications. After the final drawing pass, the following heat treatment practice was applied:

Solution heat treatment at 875°F for 1 hour,

Water Quench,

Hold at Ambient Temperature for 48 Hours,

Age at 250°F for 24 hours.

[Table 7: Composition of Alloy 4 Starting Stock (weight %)]

Zn	Mg	Cu	Zr	Ti	Cr	Sc	Al
5.09	1.83	0.316	0.115	0.023	0.055	0.071	balance

(022) As shown in Table 8, the mechanical properties of this weldable alloy variant are approximately double that of mainstay weldable aluminum alloys such as

6061 and 7005. The alloy also displays a good elongation considering the high strength levels attained.

[Table 8: Mechanical Properties of Alloy 4 Starting Stock]

Heat Treatment	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Elongation (%)
B	82.0	90.5	14.0

(023) Example 5:

Impact Extrusion Trials of Alloy 1: Alloy 1 was provided to an impact extrusion vendor in two different conditions:

Condition 1:

Cast into 7.5-inch diameter billet,

Extrude at 700°F into 2.25-inch diameter rod,

Anneal for 3 hours at 775°F, cool at 50°F per hour to 450°F and hold for 6 hours, cool to ambient temperature,

Machine into appropriate starting stock size.

Condition 2:

Cast into 2.5-inch diameter billet,

Homogenize at 800°F for 24 hours,

Machine into appropriate starting stock size

(024) Despite the fact that Alloy 1 contains a high alloying content and can attain ultra-high strength levels, the impact extrusion vendor was able to utilize the starting stock provided in Condition 1 and conduct a multi-step impact extrude/anneal cycle to achieve a hollow tube with a 2.25-inch diameter and 0.073" wall thickness. The alloy provided in Condition 2 cracked at the onset of the impact forging trial. This contrast in performance between the two conditions highlights the importance of the extrusion and annealing step for enhancing the impact extrusion capability of the starting stock. It is believed that the extrusion step serves to orient the grains along the axis of the extrusion and heals internal defects that may cause premature cracking in subsequent

impact extrusion fabrication. In any event, the fact that a highly alloyed variant can be successfully impact extruded is a remarkable achievement.

(025) Subsequent to the successful impact extrusion fabrication trial with Alloy 1 – Condition 1, the 2.25-inch diameter, 0.073-inch impact extrusion was solution heat treated at 800°F for 1.0 hour, water quenched, and aged at 250°F for 24 hours. Despite the potential for recrystallization and an accompanying strength reduction, high strength properties were attained as shown in Table 9.

[Table 9: Mechanical Properties of Alloy 1 Impact Extrusion]

Heat Treatment	**Yield Strength (ksi)**	**Ultimate Tensile Strength (ksi)**	**Elongation (%)**
B	91.3	101.4	13.5

(026) Four different alloy variants within the stated range of this invention were derived, cast, extruded into round bar, heat-treated and tested for mechanical properties. An initial assessment of the tensile properties indicated that ultra-high yield strength is attainable in the extruded product form for each of the alloy variants. While the tensile properties in the extruded product form are encouraging, the challenge to develop a starting stock for impact extrusion is to achieve two goals: 1) produce a starting stock that can be readily impact extruded into challenging geometries and 2) upon completion of impact extrusion, utilize heat treatment practices to achieve high strength properties. To design an alloy that is highly ductile and amenable to impact extrusion, the approach is to minimize the amount of alloying additions that increase strength and decrease ductility. In contrast, a part designer that is seeking a high-strength, impact-extruded component would attempt to utilize an alloy that has high alloying content. The combination of an alloy that is readily impact extruded and capable of reaching high strength levels has heretofore not been achievable.

(027) The difficulty of impact extruding a high strength alloy variant was observed when the Alloy 1 variant was cast, homogenized, machined and impact extruded. Impact extrusion of Alloy 1 could not be accomplished as cracking occurred as the impact loading was applied. Although Alloy 1 was readily extruded at an elevated temperature into round bar and heat treated to achieve high strength, the same alloy could not be impact extruded at ambient temperature. This trial underlines the difficulty of deriving an alloy that can be impact extruded and exhibit high strength. Moreover, the impact extrusion trial highlights the traditional approach for most impact-extruded parts: the impact extruder selects low-strength alloy variants that are sufficiently ductile for conversion into complex parts via impact extrusion.

(028) It is well established that aluminum alloys are much stronger in a wrought product form compared to the as-cast condition. For example, aluminum alloys such as 6061 or 7075 are not useful in the billet or ingot product form for direct use as a final part; desirable mechanical properties only achieved by various combinations of warm working and cold working to produce final product forms such as plate and extrusions. Accordingly, when alloy 1 was cast into a billet, homogenized, extruded into bar and annealed, the additional warm working applied to the billet provided starting stock for impact extrusion that was expected to prematurely fail during impact extrusion by virtue of its higher strength. Surprisingly, only the lower-strength, as-cast and homogenized starting stock failed. The extruded and annealed starting stock, despite its higher strength afforded by warm working, was successfully impact extruded into tube at ambient temperature. This unexpected result of producing a highly alloyed starting stock and providing secondary warm working and annealing was surprising as the impact extrusion was successfully accomplished. In particular, a multi-step impact extrusion sequence resulted in a very thin wall tube without cracking or premature failure.

(029) Once the unexpected accomplishment of producing a complex, thin-walled tube was performed, the next assessment was to determine whether high strength was attainable in the final part. Expectations of potential yield strength properties were set by a review of prior art related to impact extrusion. U.S. Pat. No. 4,243,438 to

Yanagida et.al. attained yield strength values as high as 28.5 ksi. Because the present invention contains a higher alloying content compared to that of Yanagida's alloy, a yield strength value greater than 28.5 ksi was predicted. U.S. Pat. No. 5,961,752, to Bergsma, reported a yield strength value of 59 ksi for an impact extrusion utilizing a 6XXX alloy.

(030) U.S. Pat. No. 5,221,377 to Hunt et.al. has an alloy range that overlaps with the present invention. Warm working processes such as rolling and extrusion followed by heat treatment produced yield strength values of approximately 90 ksi. Another warm working process, forging, was anticipated by Hunt to provide a yield strength value as high as 72.5 ksi. Hunt did not anticipate the process of impact extrusion process, nor was a suitable process for producing a suitable starting stock taught. Interestingly, the expectations of final properties for the Hunt alloy subjected to impact extrusion would be somewhat lower that anticipated for forgings or less than 72.5 ksi. Because impact extrusion is typically performed at ambient temperature, the stored energy from the impact extrusion is much greater than that generated by a warm working operation such as forging. This increased stored energy is the driving force for a higher amount recrystallization during subsequent solution heat treatment. Accordingly, the impact extrusion yield strength of Hunt's alloy formulation would be expected to be somewhat less than 72.5 ksi.

(031) As shown in Table 9, a heat treatment for the Alloy 1 impact extrusion resulted in a remarkable yield strength level of 91.3 ksi. This strength level far exceeds the 28.5 ksi yield strength attained by Yanagida and the 59 ksi yield strength level attained by Bergsma. Hunt did not anticipate a method to successfully produce impact extrusion starting stock nor a suitable means to achieve a high strength impact extruded product; a forging was expected to achieve a yield strength of 72.5 ksi, thus a cold-working operations such as impact extrusion would be expected to provide a yield strength less than 72.5 ksi. In contrast, this invention uncovered a method to successfully produce an impact extrusion and achieve a yield strength value of 91.3 ksi in the final part. This dual accomplishment of good impact extrusion capability and properties that

far exceed those reported or even anticipated will result in numerous applications for high strength impact extruded components.